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INITIATION OF EXPLOSIVES BY EXPLODING WIRES

VIII. Survey to Determine Explosives Capable of Initiation at Moderate Voltage Levels

17 NOVEMBER 1965

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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INITIATION OF EXPLOSIVES BY EXPLODING WIRES

VIII. Survey to Determine Explosives Capable of Initiation at Moderate Voltage Levels

By

Howard S. Leopold

ABSTRACT: The explosives: PETN, TNETB, RDX, HNAB, DINA, BTNES, HNH, and HMX can be initiated high order by a 2-mil diameter gold wire exploded by a 1-microfarad capacitor charged to 4000 volts. These explosives are rated as fairly sensitive secondary explosives by the impact test. PETN exhibits the fastest build-up to detonation of the explosives that initiated.

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EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
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INITIATION OF EXPLOSIVES BY EXPLODING WIRES
VIII. Survey to Determine Explosives Capable of Initiation at Moderate Voltage Levels

This report is Part VIII of an investigation concerning the initiation of explosives by exploding wires. The work was performed under Task RMMO-62-059/212-1/F008-08-11, Problem No. 9, Analysis of Explosive Initiation.

The results should be of interest to personnel engaged in initiation research and in the design of exploding bridgewire ordnance systems.

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J. A. DARE
Captain, USN
Commander

C J Aronson

C. J. ARONSON
By direction

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INTRODUCTION

1. This is the eighth report* in a series describing experimental results obtained from an investigation of the interaction between exploding wires and explosives. Previous investigation has dealt largely with the determination of the optimization of some of the wire and circuit parameters. PETN (pentaerythritol tetranitrate) was chosen as the test explosive during the investigation of the electrical characteristics because it was the most commonly used explosive in EBW devices at the time the investigation started. Lately, the use of RDX (cyclotrimethylenetrinitramine) in EBW devices has increased because of its better heat resistant properties and its lower shock sensitivity. There is also increasing interest in exploring the possibility of using other explosives to take advantage of desirable properties such as, for example, radiation resistance.

2. This phase of the investigation consisted of a survey to determine what explosives might be initiated with moderate voltage levels of 2000 and 4000 volts. These voltage levels, which are well within the present state of the EBW firing unit art (without entailing excessive insulation) correspond to storage energy levels of 2 and 8 joules when using a 1-microfarad capacitor. The manner of growth to detonation also was observed for those explosives which propagated to determine if the growth pattern would permit use within the usual dimensions characteristic of EBW initiators.

ELECTRICAL CIRCUITRY

3. The test circuit used for this investigation is shown in Figure 1. It is similar to the previous test circuits described in earlier reports except that an EG&G KN-4 Kryton trigger tube was used as the switching device since it is capable of firing at both the 2000-and 4000-volt test levels. The circuit parameters for this test circuit are:

$C = 0.97$ microfarad

$L = 0.70$ microhenry

$R = 0.40$ ohm

$V_o = 2000$ or 4000 volts

* Other reports on this series are listed on Page 7

The methods used for determining the circuit parameters are given in References 1 and 2.

TEST PROCEDURE

4. Various available secondary explosives were tested at 2000-and 4000-volt charging levels with the test circuit. The explosive samples were, if possible, <325 mesh (44 microns or less in size) and were obtained by screening of the original samples. The density of each test explosive was kept close to 50% of its crystal density. At least 2 test shots were made for each explosive at the 4000-volt level. If propagation occurred, the explosive was also tested at the 2000-volt level. PETN was re-tested along with the other explosives for a comparison of the growth to detonation characteristics.

5. The test fixture and experimental methods described in References 1 and 2 were used for observing the growth of explosion. The bridgewire for both test levels was a gold wire of 2-mil diameter and 75-mil length.

WIRE PHENOMENA

6. The gold bridgewire used (2-mil dia. x 75-mil length) requires a calculated 0.163 joule for complete vaporization, based on handbook constants. At the 2000-volt charging level, the bridgewire dimensions are closely matched to the circuit parameters for efficient explosion of the wire [3,4]; wire burst* occurs approximately two-thirds up the leading edge of the current pulse. The bridgewire bursts at $\approx$ 0.58 microsecond at which time $\cong$ 72% of the calculated vaporization energy has been deposited. This bridgewire, when exploded while suspended in distilled water generated a shock velocity in the water of 1610 meters/sec at the wire's midpoint. This velocity is equivalent to a water pressure of 1.02 kilobars.

7. At the 4000-volt charging level, the bridgewire explodes at $\approx$ 0.42 microsecond at which time $\cong$ 138% of the calculated vaporization energy has been deposited. This is almost double the energy deposited at the 2000-volt charging level. However, more efficient utilization of the available energy would be expected with a larger diameter bridgewire since four times the stored energy at the 2000-volt level is available. At the 4000-volt level, the shock velocity in distilled water is 1690 meters/second; equivalent to a water pressure of 1.78 kilobars. The peak current density in the bridgewire just before burst is 7×10^7 amperes/cm^2 at the 4000-volt level compared to 5×10^7 amperes/cm^2 at the 2000-volt level.

* Burst time is considered to be the average of the time of the first apparent deflection of the current waveform and the time of the voltage peak.

EXPERIMENTAL RESULTS

8. Twenty three available explosives (18 in the open literature and 5 classified explosives) were first tested at the 4000-volt charging level. None of the classified explosives initiated high order with the type of confinement employed. Eight of the open literature explosives initiated high order. These eight were then re-tested at the 2000-volt charging level to determine if they would initiate high order at the lower energy level. See Tables I and II for selected properties of the test explosives and a summary of the results of the open literature test explosives.

9. The growth to detonation characteristics were observed for those explosives which propagated. When propagation occurred at both the 2000-and 4000-volt levels, the growths to detonation for both initiation levels were compared.

PETN PETN gave the fastest build-up of the explosives that initiated high order. The growth of detonation was similar for both test levels. The growth at the 2000-volt level lags that of the 4000-volt level by 0.1 µsec with photographic observation of the wire burst considered as zero time for both test levels. At a 6-mm distance from the bridgewire, the detonation velocity averaged 4.14 mm/µsec for both test levels. See Figure 2.

TNETB TNETB propagated at both test levels with an accelerating detonation, though slower than PETN. At a 6-mm distance from the bridgewire, the velocity was 2.77 mm/µsec for the 4000-volt test level and 2.62 mm/µsec for the 2000-volt test level. The growth at both test levels was similar. See Figure 3.

BTNES BTNES propagated at both test levels with a similar growth for each test level. The growth at the 2000-volt level lagged that of the 4000-volt level by 0.25 microsecond. At a 6-mm distance from the bridgewire, the detonation velocity averaged 2.27 mm/µsec for both test levels. See Figure 4.

DINA DINA propagated at both test levels. The growth at the 2000-volt test level was slower than at the 4000-volt level. At a 6-mm distance from the bridgewire, the velocity was 2.70 mm/µsec for the 4000-volt test level and 2.09 mm/µsec for the 2000-volt level. See Figure 5.

HNAB The growth of detonation of HNAB differed at the two test levels. At the 4000-volt level, HNAB exhibited an accelerating growth reaching a velocity of 2.21 mm/µsec at a 6-mm distance from the bridgewire. At the 2000-volt level, HNAB exhibited a reaction rate of 0.67 mm/µsec for 5 to 6 microseconds and then underwent an abrupt transition to a constant detonation velocity of 4.4 mm/µsec approximately 6-mm from the bridgewire. See Figure 6.

The lower energy input was observed to result in a faster detonation velocity at a shorter distance from the bridgewire. However, the time period to reach this velocity was erratic and of a longer duration.

RDX Three available different types of RDX were tested. Sub-sieve (<44 microns) Wabash RDX, sub-sieve Holston RDX (7-8% HMX), and a Holston 2-micron RDX were evaluated. All three types initiated high order at both test levels. The sub-sieve Holston RDX gave the fastest rate of growth and had the highest velocity 6 mm from the bridgewire. The 2-micron RDX gave the slowest build-up. (see Figure 7). Although the grain burning theory implies that a high surface to volume ratio is desirable, the results with the 2-micron RDX indicate that too fine a particle size may not be desirable.

HMX At the 4000-volt level, HMX gave a slowly accelerating reaction with a velocity of 1.16 mm/μsec at a 6-mm distance from the bridgewire. (see Figure 8). HMX did not propagate at the 2000-volt level; only a small cavity was burned into the explosive.

HNH HNH also propagated only at the 4000-volt level. At a 6-mm distance from the bridgewire, the velocity was 1.71 mm/μsec and was slowly accelerating. A small void was burned into the explosive at the 2000-volt level. (see Figure 9).

OTHER EXPLOSIVES The test shots, if propagation did not occur, usually resulted in a cavity in the bridgewire area apparently due to a combination of some combustion and melting of the explosive. An exception to this was nitroguanidine. No cavity was observed with nitroguanidine. The nitroguanidine remained in clumps of needle-like crystals with a purplish hue apparently due to colloidal gold dispersed by the exploding bridgewire. Both graphited and plain tetryl exhibited more burning than the other explosives which did not propagate. Large cavities were burned in the pressed explosive. The entire amount of DNPN in the test fixture burnt, leaving a black char residue.

DISCUSSION

10. The process by which energy is transferred from an exploding wire to a surrounding explosive is not as clearly understood as it is for initiation from a hot wire. An exploding wire can produce:

(1)	Intense light	(5)	Plasma
(2)	Shock energy	(6)	Electrons
(3)	Liquid droplets	(7)	Electric discharge
(4)	Hot vapor	(8)	Kinetic energy

Lead azide can be initiated by weak pseudo exploding wires which form only large molten droplets. Past experiments have indicated that stronger exploding wires can initiate PETN by a combination of energy forms such as shock energy, conductive heat transfer, and kinetic energy or if the wire explosion is strong enough, by shock energy alone.[6] Thus, the primary stimulus causing initiation can change with the intensity of the wire explosion. In general, initiation is considered thermal in origin.[6] The mechanism of the degradation of the stimulus energy into heat must be known before quantitative measurements can be attempted.[7] Since the mechanism of degradation into heat depends upon the nature of the stimulus, it has become customary to talk of different types of sensitivity.[8] With exploding wires, we are dealing with an initiation process in which one or more different energy forms can contribute.

11. Coupled with the difficulties of quantitatively defining the stimulus is the observation that the amount of energy required for the initiation of an explosive varies with the physical characteristics of the explosive. The particle size, density, and confinement can influence the energy needed for initiation. For this investigation, the explosives were tested under conditions which were favorable for initiating PETN (i.e., fine granulation, and about 50% theoretical maximum density). In the test fixture used propagation depends strongly on the wire stimulus and only little on the confinement. Dimensions of the test fixture exceed reported critical diameters for the granular form of the more insensitive test explosives. However, the critical diameter increases as the explosive density decreases and the sparse amount of critical diameter data available are for densities higher than employed in these experiments.

12. The impact test, in which a weight is dropped on the test explosive from varying heights, has been used for many years to determine the relative sensitivity of explosives. Although complex, the impact initiation mechanism does not appear to be one of pure shock. Though there is some uncertainty associated with the test, the impact sensitivities agree in general with field handling and accident experience since the majority of accident observations result from mechanical impact initiations. Wenograd has proposed that the impact sensitivities of organic high explosives are related to the velocities of their thermal decomposition reactions at very high temperatures.[8] In this initial survey at moderate voltage levels, explosives that are initiated high order by the exploding wire correspond to those rated as the more sensitive by the impact test. (see Table 1). The only relatively impact sensitive explosive found not to propagate, DNPM, burned completely in the test fixture. Aside from sensitivity, another important characteristic of explosives suitable for use in exploding bridgewire devices, is their ability

to build up to detonation within the limited dimensions of EED's. The build-up patterns of HMX and HNH, which required higher initiation energies than the other explosives which propagated, indicate that larger dimensions may be required for EBW devices employing the more insensitive explosives. Since the initiation of the more insensitive explosives is likely to entail higher voltage levels also, the larger dimensions if necessary will have at least the advantage that more space will be available for insulation. Table III gives the observed detonation velocities at a 6-mm distance from the wire. It can be seen that the observed velocities of all the test explosives at this distance are still below the ideal detonation velocity.

CONCLUSIONS

1. PETN, TNETB, RDX, HNAB, DINA, BTNES, HNH, and HMX can be initiated high order at moderate voltage levels by an exploding wire.

2. PETN exhibits the fastest build-up to detonation of the secondary explosives that initiated high order.

3. Explosives that were initiated high order by exploding wires at moderate voltage levels correspond to those rated as the more sensitive by the impact test.

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OTHER REPORTS IN THIS SERIES

1. Reference 1 above
2. Reference 2 above
3. Reference 3 above
4. Reference 4 above
5. V Effect of Wire Material on the Initiation of PETN by Exploding Wires NOLTR 64-146
6. VI Further Effects of Wire Material on the Initiation of PETN by Exploding Wires NOLTR 65-1
7. Reference 5 above

TABLE I. Properties of Test Explosives

Symbol	Name	Melting Point (°C)	Crystal Density (g/cm^3)	50% Impact Height[1] (cm)
PETN	pentaerythritol tetranitrate	141	1.77	12
TNETB	trinitroethyltrinitrobutyrate	93	1.78	20
RDX	cyclotrimethylene trinitramine	204	1.82	24
DNPN	dinitropropylnitramine	188 d	1.73	9-32
HNAB	hexanitroazobenzene	222	1.7	27
DINA	diethylnitramine dinitrate	54	1.70	27
BTNES	bistrinitroethylsuccinate	125	1.68	30
HNH	hexanitroheptane	132	1.70	28-34
HMX	cyclotetramethylenetetranitramine	273	1.90	32
EDNA	ethylenedinitramine	175 d	1.71	33
Tetryl	methyltrinitrophenylnitramine	130	1.73	40
DNPTB	dinitropropyltrinitrobutyrole	95	1.68	28-250[2]
TACOT[3]	tetranitrodibenzo tetrazapentaline	410 d	1.85	85
TNB	trinitrobenzene	121	1.69	103
TNT	trinitrotoluene	81	1.65	210
Exp D	ammonium picrate	265 d	1.72	235
TATB	triaminotrinitro benzene	440 d	1.94	>320
NQ	nitroguanidine	232	1.72	>320

[1] 2.5 kg.wt., type 12 tools, sandpaper 5/0

[2] Varies widely in sensitivity due to variations of crystal form

[3] Trade name, E. I. duPont Company

d - decomposition

TABLE II. Results of Explosive Survey

Explosive	Particle size (microns)	Test Density g/cm^3	% of TMD	2000 volts H.O.	2000 volts L.O.	4000volts H.O.	4000volts L.O.
PETN	<44	0.9	51	2	0	2	0
TNETB	<44	0.9	51	2	0	2	0
RDX(Holston)	<44	0.9	49	2	0	2	0
RDX(Wabash)	<44	0.9	49	2	0	2	0
RDX	2	0.9	49	2	0	2	0
DNPN	<44	0.9	52	-	-	0	2
HNAB	<44	0.9	53	4	0	3	0
DINA	<44	0.9	53	2	0	2	0
BTNES	<44	0.9	54	2	0	2	0
HNH	<44	0.9	53	0	2	2	0
HMX	<44	1.1*	58	0	2	2	0
EDNA	<44	0.9	53	-	-	0	2
Tetryl	<44	0.9	53	-	-	0	2
Tetryl(graphited)	<44	0.9	53	-	-	0	2
DNPTB	<44	0.9	54	-	-	0	2
TACOT-Z	<44	0.9	49	-	-	0	2
TACOT-T	<44	0.9	49	-	-	0	2
TNB	<44	0.9	53	-	-	0	2
TNT	<44	0.9	55	-	-	0	2
Explosive D	<44	0.9	52	-	-	0	2
NQ	Unscreenable	0.9	52	-	-	0	2
NQ	Unscreenable	0.7	41	-	-	0	2
NC	Unscreenable	0.5	29	-	-	0	2
TATB	<44	0.9	46	-	-	0	2

* Lowest density that would completely fill test fixture

TABLE III. Observed Propagation Velocity of Test Explosives 6 mm from Bridgewire

Explosive	Ideal Detonation Velocity (meters/sec)	Density (g/cm^3)	2000-Volt Test Level Velocity (meters/sec)	2000-Volt Test Level Elapsed Time[1] (microsec)	4000-Volt Test Level Velocity (meters/sec)	4000-Volt Test Level Elapsed Time[1] (microsec)
PETN	5160	0.9	4170	2.00	4110	1.90
TNETB	5060	0.9	2620	3.60	2770	3.25
RDX(Holston)	5720	0.9	2820	3.35	2930	3.10
RDX(Wabash)	5720	0.9	1810	4.15	1800	3.85
RDX(2 micron)	5720	0.9	1630	4.55	1760	4.15
HNAB	[2]	-	4400[3]	6.0[3]	2210	4.00
DINA	5760	0.9	2090	4.40	2700	3.30
BTNES	4970[4]	0.9	2250	3.75	2300	3.35
HNH	[2]	-	-	-	1710	4.35
HMX	6370	1.1	-	-	1160	5.50

1 Time required for propagation to travel 6 mm, zero time = wire burst
2 Data not available
3 Average of scattered values
4 Scaling relation not known, slope of 3500 assumed with reference of 7700 meters/sec at 1.68 g/cm^3

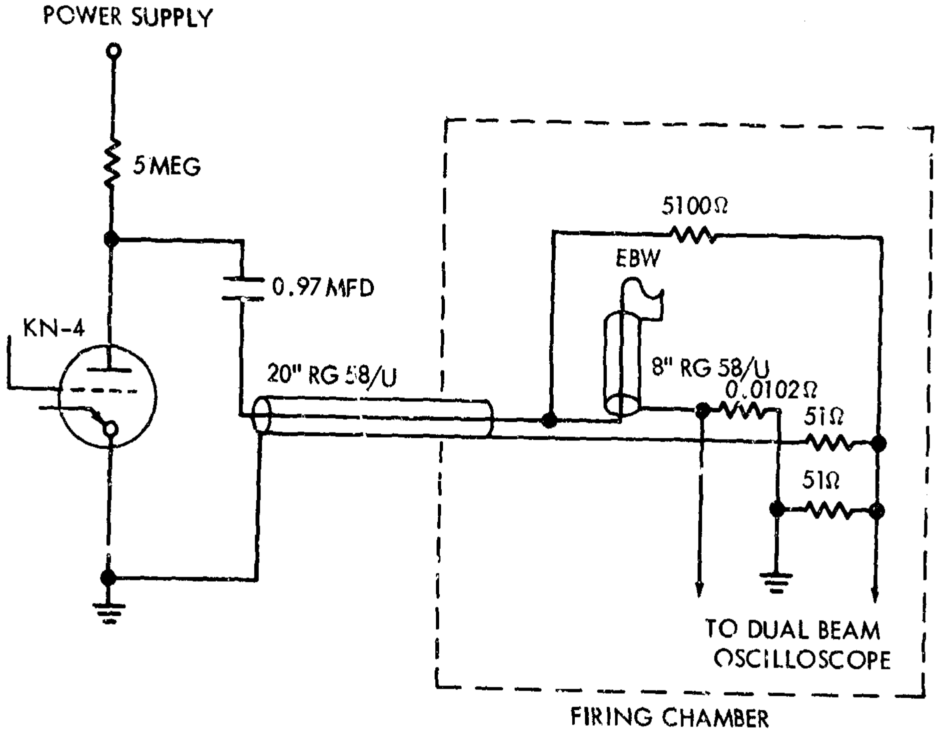

FIG. 1 TEST CIRCUIT

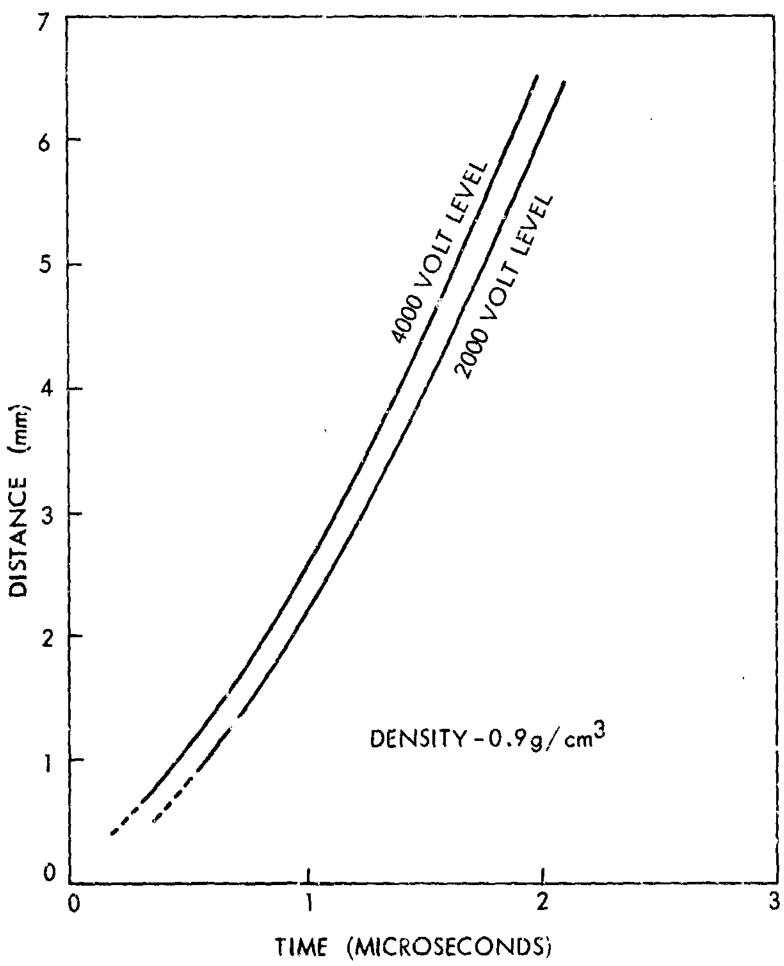

FIG. 2 GROWTH OF DETONATION IN PETN

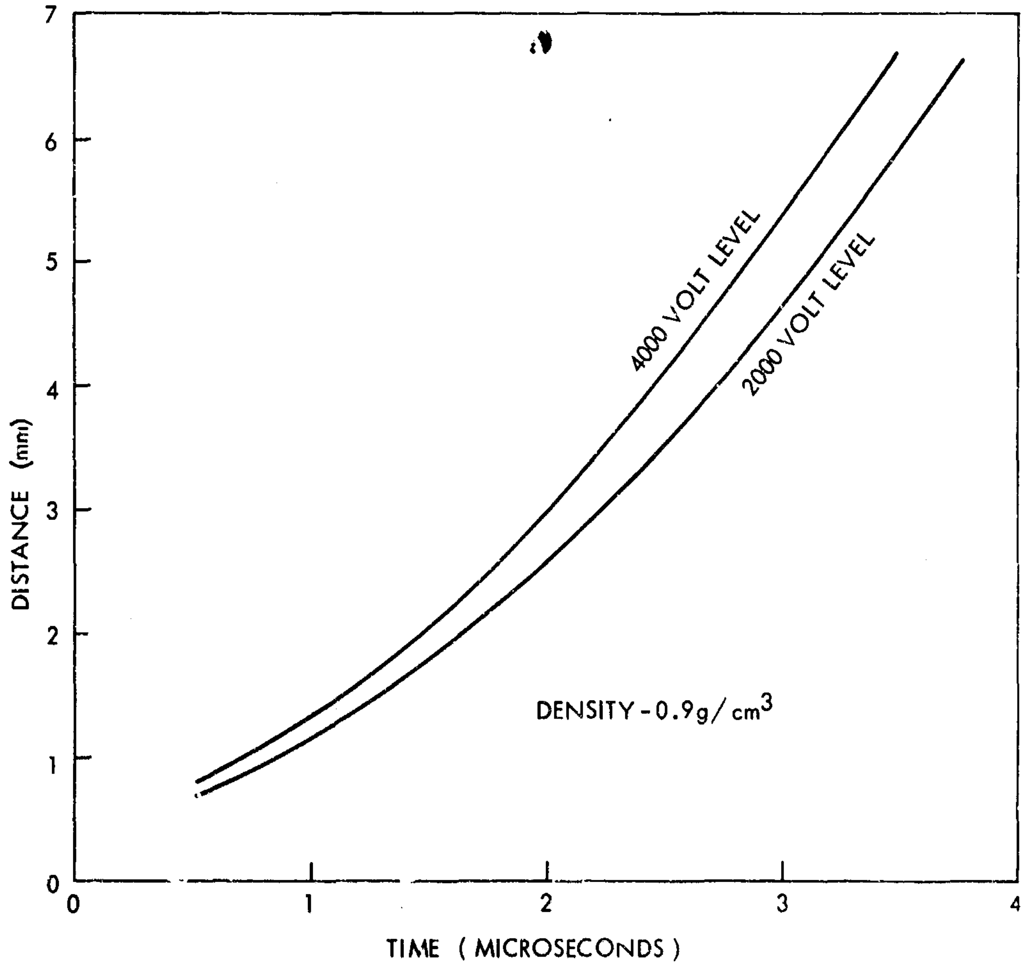

FIG. 3 GROWTH OF DETONATION IN TNETB

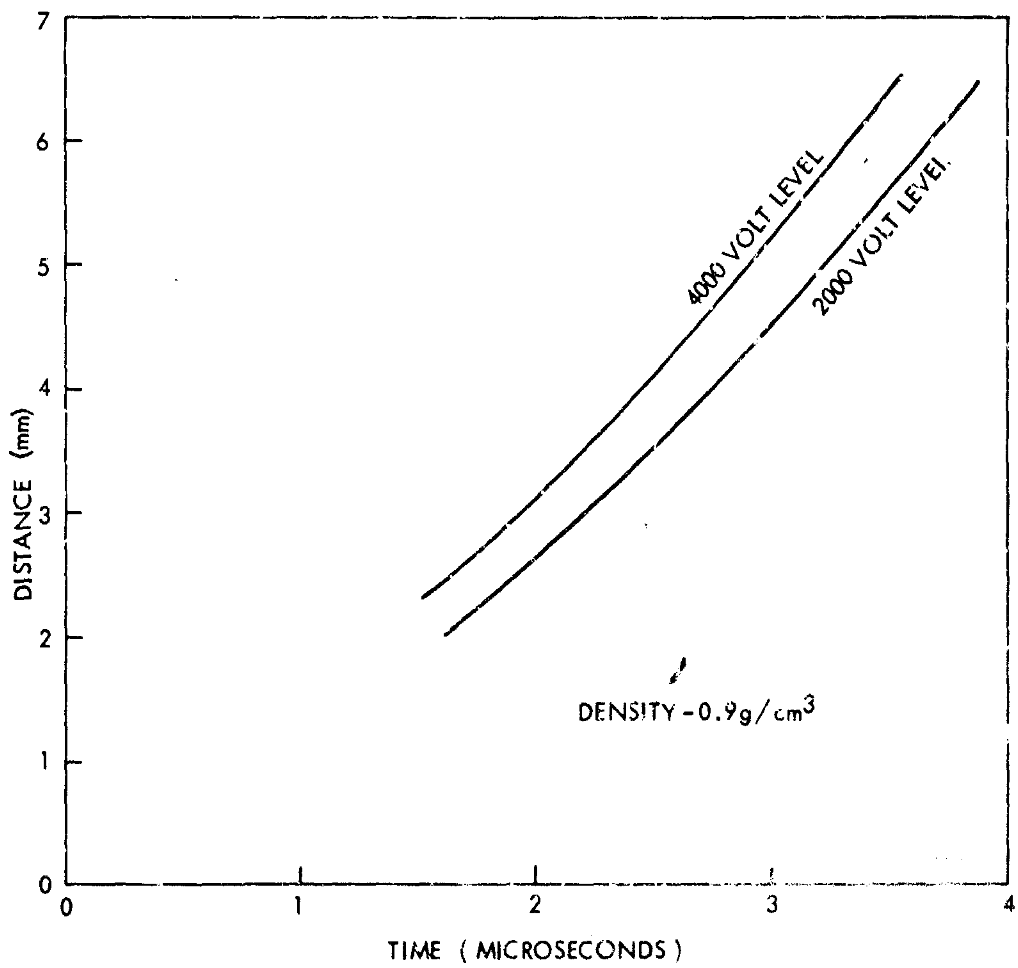

FIG. 4 GROWTH OF DETONATION IN BTNES

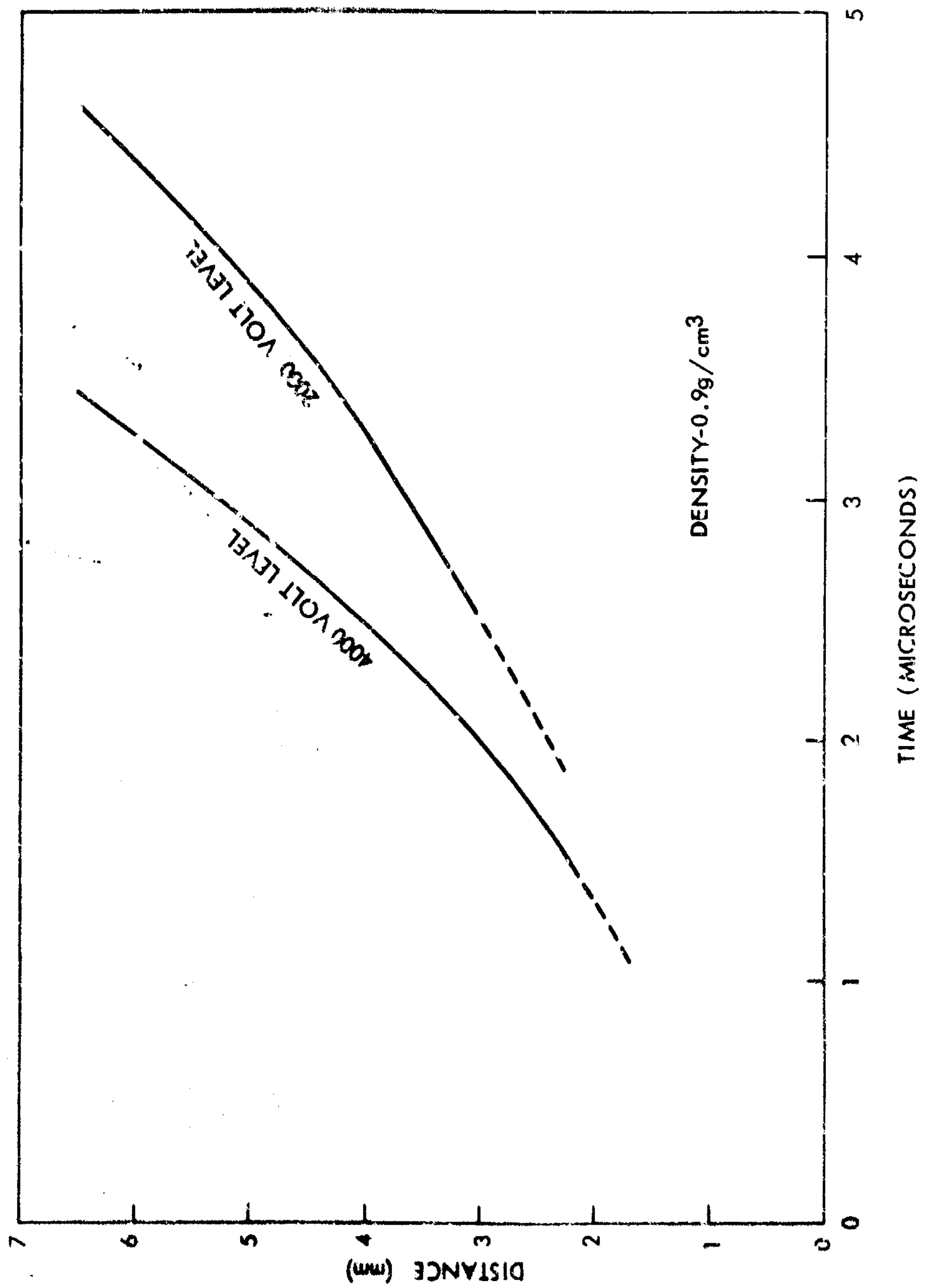

FIG. 5 GROWTH OF DETONATION IN DINA

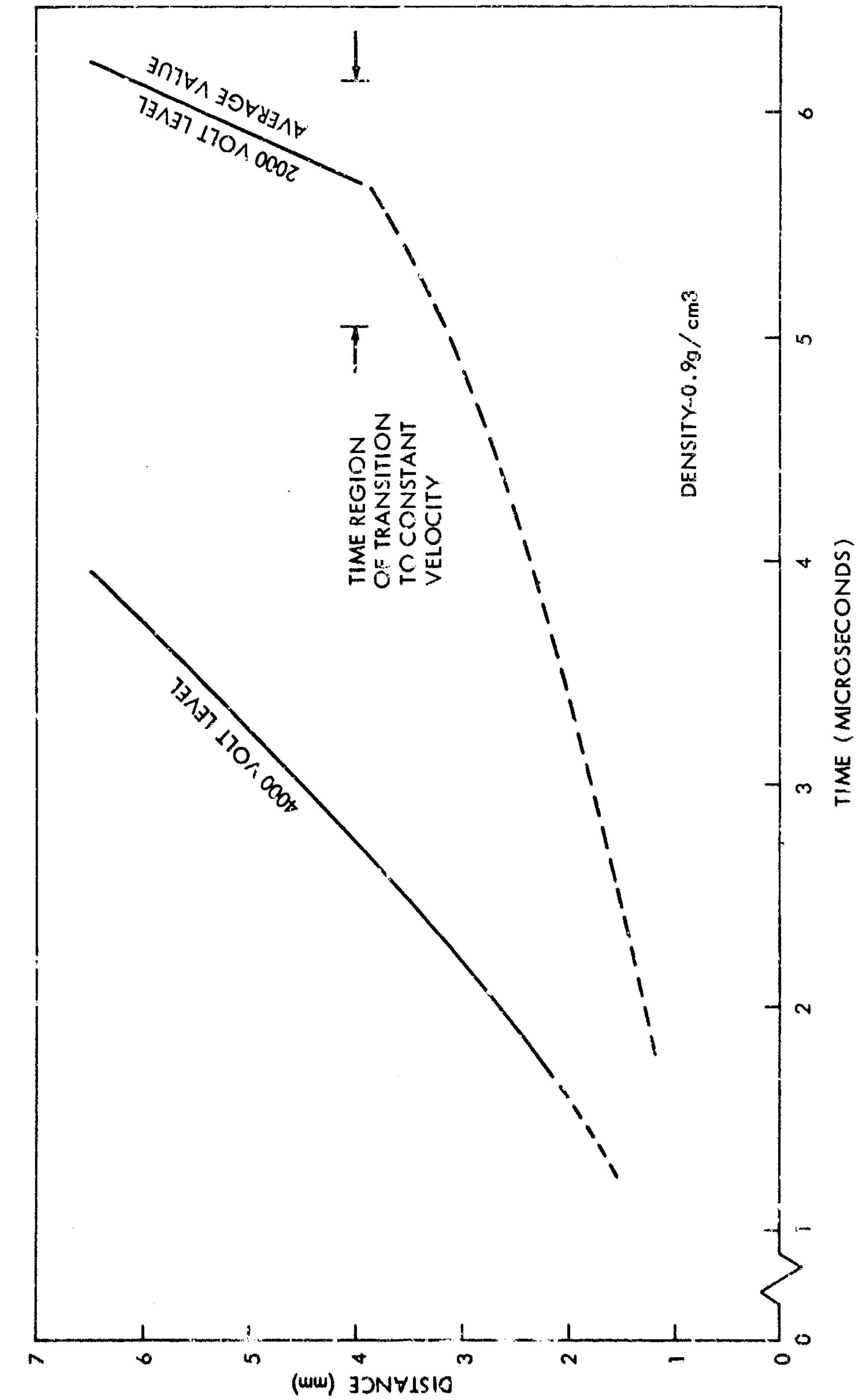

FIG. 6 GROWTH OF DETONATION IN HNAB

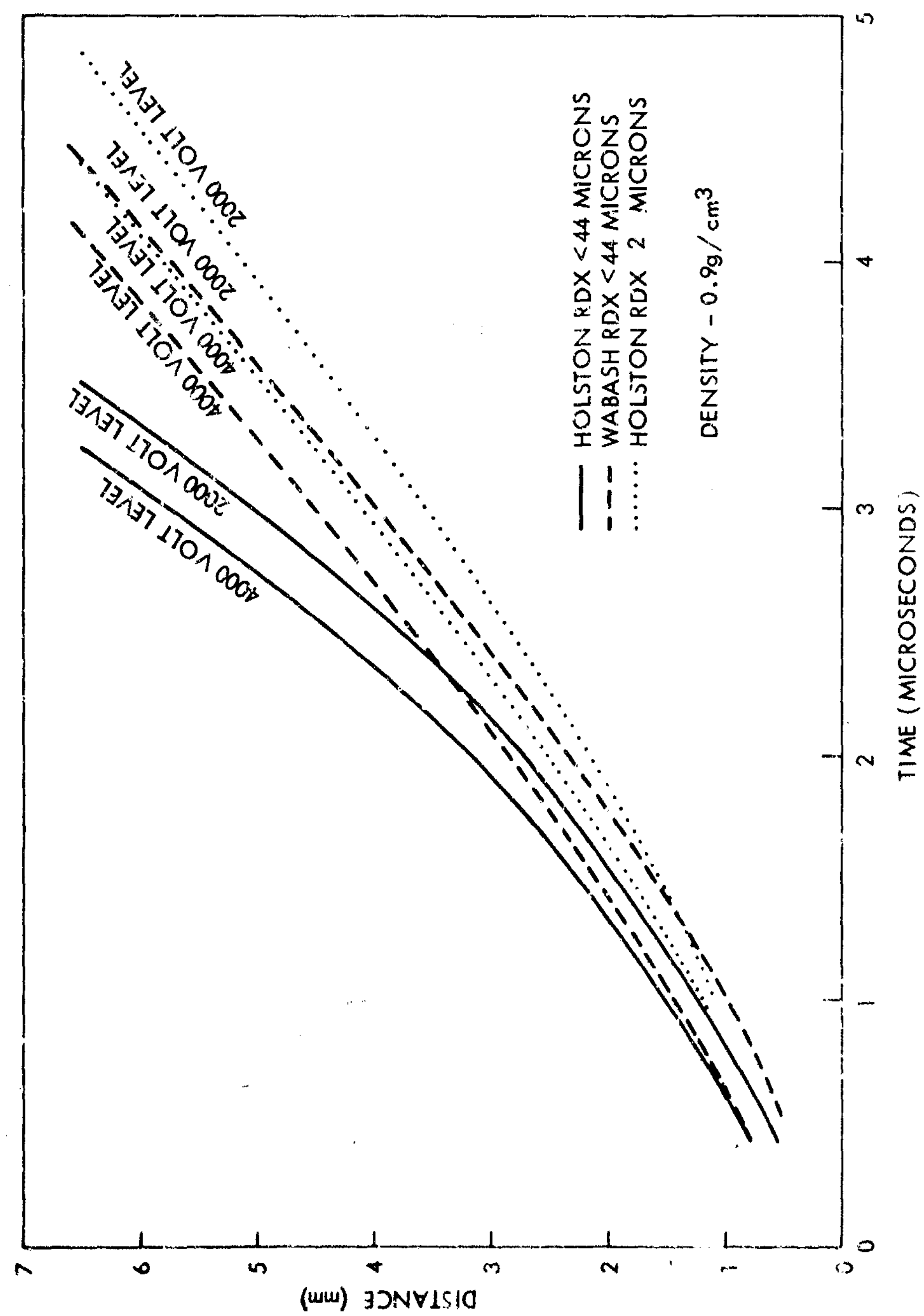

FIG. 7 GROWTH OF DETONATION IN RDX

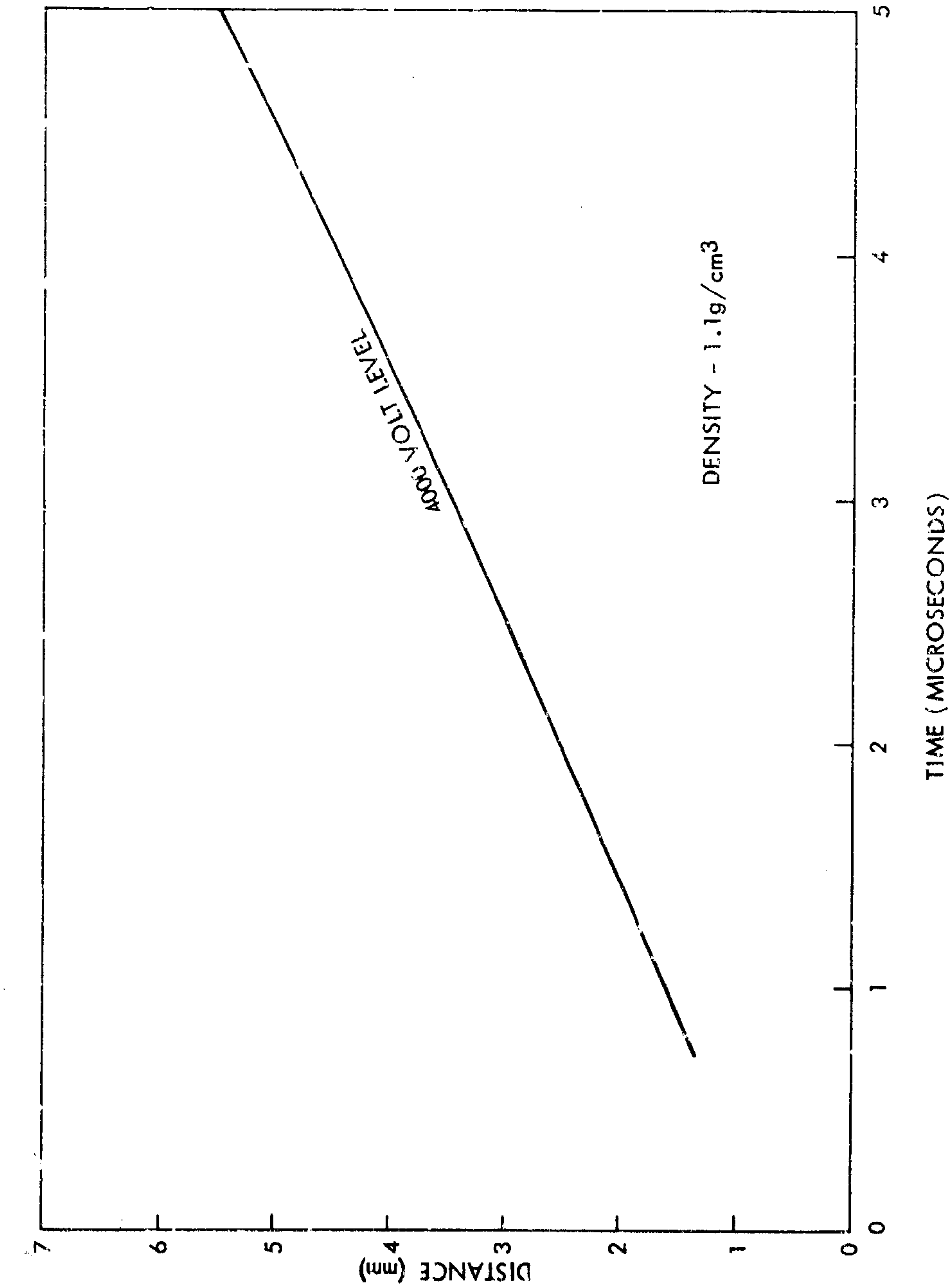

FIG. 8 GROWTH OF DETONATION IN HMX

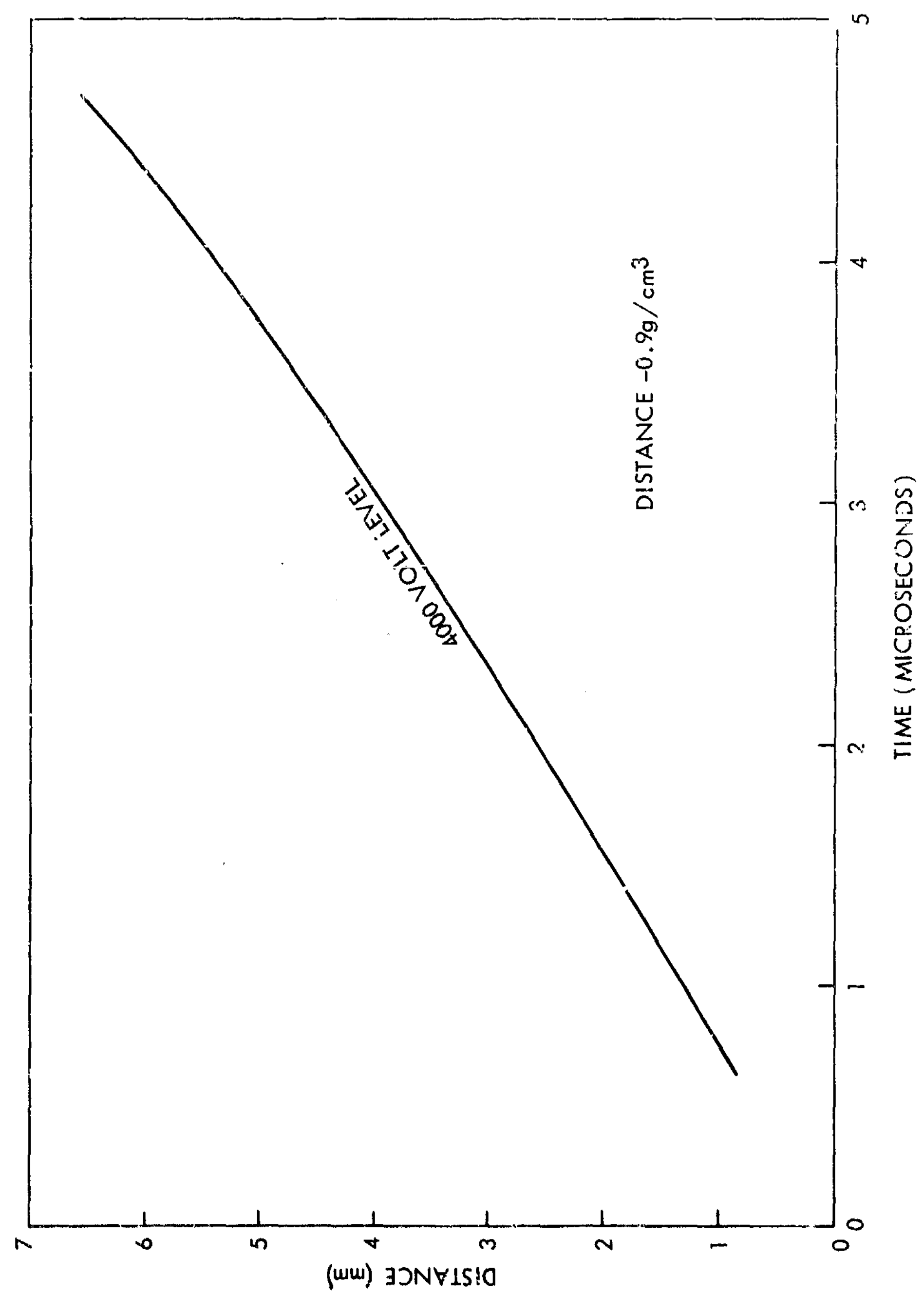

FIG. 9 GROWTH OF DETONATION IN HNH